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TRANSPONDER PERFORMANCE ANALYZER (TPA).(U)
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LEVEL II

TRANSPONDER PERFORMANCE ANALYZER (TPA)

Carl Hazelwood

OCTOBER 1979

FINAL REPORT

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

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16. Abstract

The purpose of this document is to describe the Transponder Performance Analyzer (TPA) used for measurement of aircraft beacon transponder performance characteristics. The system was developed at NAFEC utilizing both "in-house" designed and commercially available equipment. The system is fully self-supporting, is housed in a mobile bus, and has been used for ramp testing of transponders operating in general aviation aircraft and for bench testing of "off-the shelf" units.

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METRIC CONVERSION FACTORS

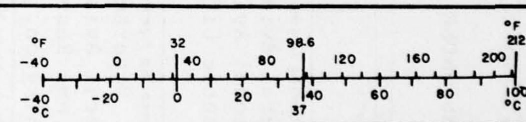
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

The evolution and development of automated air traffic control (ATC) systems have provided substantial improvements in air safety, traffic flow, efficiency, and utilization of the national airspace. A major part of the improvements has been in the development of automatic data acquisition and reporting systems. One such system is the air traffic control radar beacon system (ATCRBS) which determines aircraft position, altitude, and identity. These parameters are critical to aviation safety and effective, efficient ATC. The operational performance characteristics of the various systems and equipment processing these parameters are then of extreme importance to public safety, ATC, and the Federal Aviation Administration (FAA).

Determination of these performance characteristics requires comprehensive techniques for measurement and analysis. The Transponder Performance Analyzer (TPA), described herein, is a system designed and developed explicitly for statistical data collection and analysis of airborne beacon transponder performance characteristics. The TPA was not designed nor intended to perform any type of certification tests in exact conformance with the national standard.

ATCRBS GENERAL DESCRIPTION

The accelerated growth of aviation has far exceeded the capabilities of the unaided air traffic controller. As a result, ATC systems and equipment have evolved from simple manual control, to primary radar-aided control, to sophisticated data acquisition, computer processing, and display systems. This evolution, however, requires more precision and reliability of the data and equipment involved. Primary radar provides aircraft information in terms of distance (range) and angle (azimuth) from the radar site, but does not provide aircraft identity and altitude information. Further, primary radar is an analog system subject to ground clutter, weather, scintillation, and radar cross section, and hence requires wide separation criteria for safe ATC. The use of ATCRBS can avoid or minimize most of these problems.

Unlike primary radar, which is passive as far as the aircraft is concerned, the ATCRBS (also referred to as "secondary surveillance radar" (SSR)) is a cooperative system and requires an active device onboard the aircraft to respond to ground-based interrogations (see figure 1). These interrogations are very specific, rigidly controlled radiofrequency (RF) pulse groups (code trains) transmitted by the ground equipment (on 1030 megahertz (MHz)) to interrogate all aircraft within the area of coverage. Upon interrogation, the aircraft beacon receiver (transponder) transmits a coded reply pulse train back to the ground station on a different frequency (1090 MHz). This reply contains the aircraft identity selected by the pilot and, when the aircraft is properly equipped and interrogated, the aircraft altitude. The ground-based equipment can then automatically decode the information and

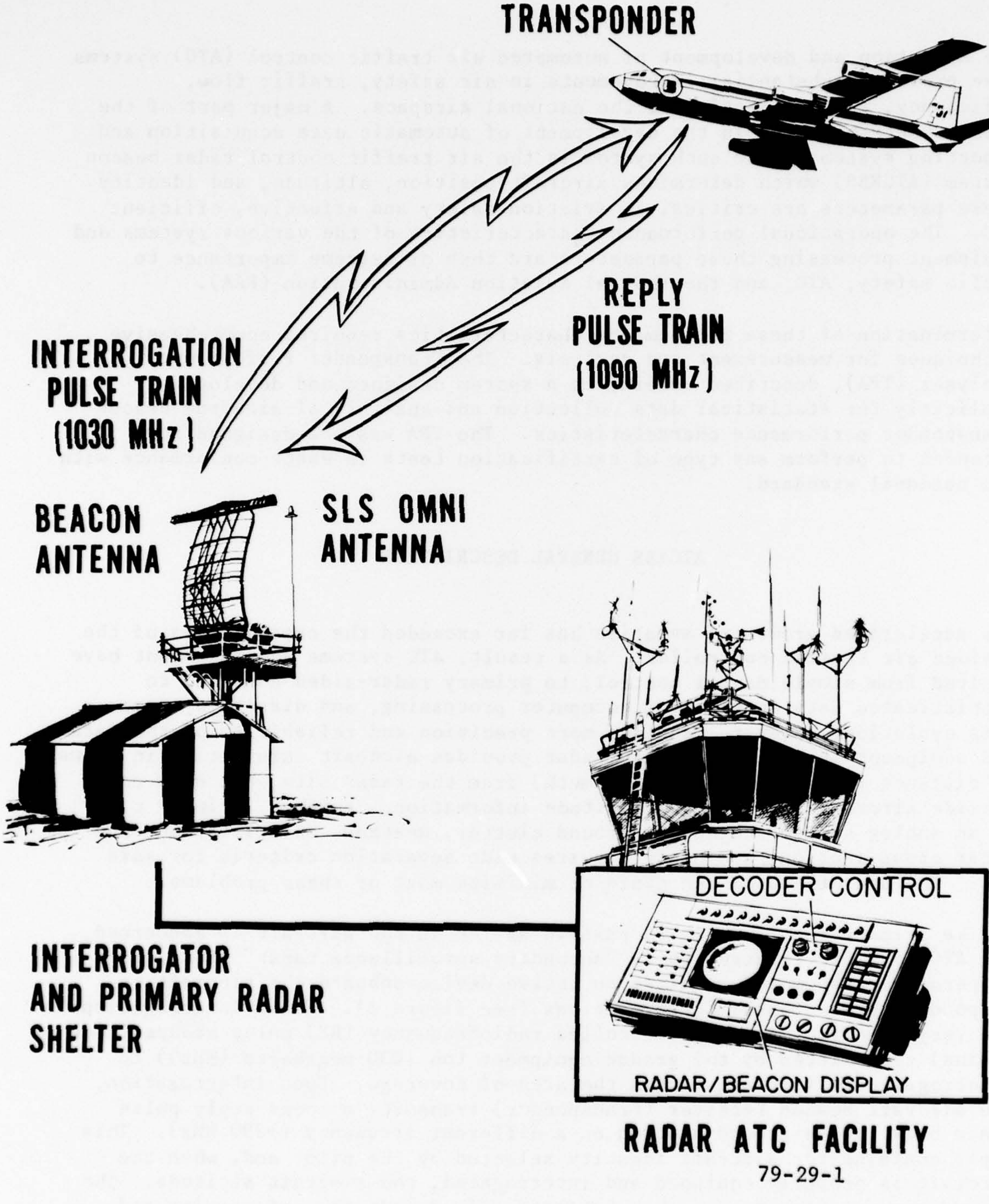


FIGURE 1. AIR TRAFFIC CONTROL RADAR BEACON SYSTEM

determine the aircraft range, azimuth, identity, and altitude. The cooperative equipment onboard the aircraft provides stronger signal replies than radar skin paints and eliminates ground clutter by replying on a frequency different from that of the interrogation. Discrete aircraft emergency codes are also provided in the ATCRBS system.

The ATCRBS actually consists of a ground-based rotating directional antenna system, an interrogator/receiver, signal processing equipment, and active aircraft transponders. In operation, the interrogation pulse-group is transmitted from the directional antenna and triggers each airborne transponder located in the directional main beam as the antenna rotates or scans by the aircraft. Measurement of the signal round-trip transit time (the interrogation and reply) determines the range (rho), and the mean direction of the interrogator antenna during aircraft replies determines the azimuth (theta) of the replying aircraft.

ATCRBS PULSE TRAIN DESCRIPTION

A brief description of both the interrogation and reply pulse train is required in order to understand the TPA. More detailed information and specifications for both interrogation and reply are contained in FAA Order 1010.51A "U.S. National Aviation Standard for the Mark X (SIF) Air Traffic Control Radar Beacon System (ATCRBS) Characteristics," and Radio Technical Commission for Aeronautics (RTCA) documents; DO-144, "Minimum Operational Characteristics (MOC); Airborne ATC Transponders" and DO-150, "Minimum Performance Standards (MPS), Airborne ATC Transponders."

INTERROGATION.

The basic interrogation consists of pulse pairs (P1 and P3) which are transmitted by the rotating directional antenna normally at a repetition rate of several hundred pairs per second. These pulses are nominally of equal amplitude and are separated by time intervals dependent on the mode of interrogation (see figure 2). The primary modes of interest for purposes of this document are the mode 3/A (identity) and mode C (altitude). The other modes are not used in the civil ATC system and will not be considered in this description. The time interval or separation between P1 and P3 in mode 3/A is 8 $\pm$0.2 microseconds (μs). The aircraft transponder decodes this time interval as an "identity" interrogation and responds with the aircraft beacon code selected by the pilot. The time separation for a mode C altitude interrogation is 21 $\pm$0.2 μs. Again, this interval is decoded, and the transponder replies with the aircraft altitude derived from a pressure altimeter, air data computer, or other device.

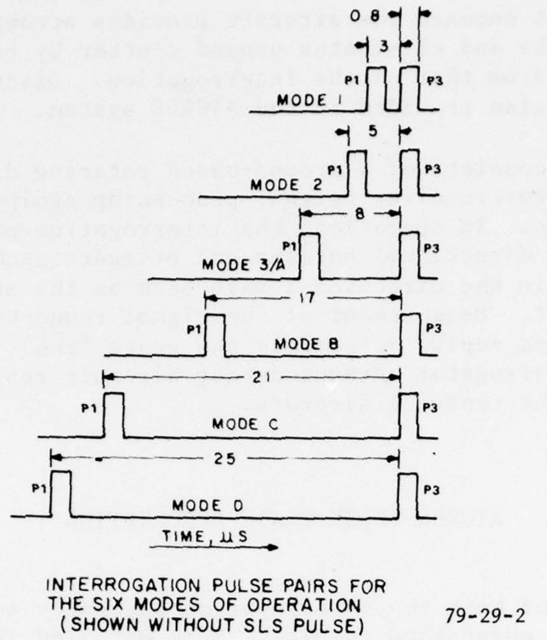
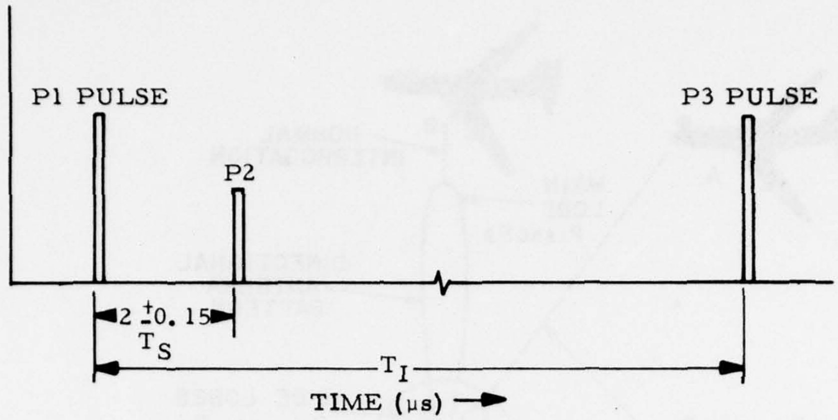


FIGURE 2. TIME INTERVALS BETWEEN PULSES

The above interrogation pulses, P1 and P3, would provide proper operation under ideal circumstances and conditions; however, the real world environment is far from ideal and presents many problems. Among these are imperfections in the pattern of RF energy radiated from the directional antenna (side lobes), reflections of the radiated energy from nearby objects, and interference from other sources. In order to alleviate these problems, a third pulse (P2) is transmitted from an omnidirectional antenna to suppress or inhibit replies from transponders which might otherwise be triggered. The P2 pulse occurs 2 ± 0.15 µs after the P1 pulse (see figure 3) and is transmitted at a power level such that the P2 energy at the aircraft receiving antenna is greater than the P1-P3 energy from the side lobes (see figure 4). In figure 4, the directional antenna, hence the main beam, is pointing directly at aircraft B for a normal interrogation, and the power level of P1 and P3 received by aircraft B is much greater than the P2 power level received from the omni antenna. Aircraft B transponder detects the power level of P1 as being much greater than P2 and responds with the normal reply.



$T_I = 8 \pm 0.2\mu s$ (MODE 3/A)

$= 21 \pm 0.2\mu s$ (MODE C)

$T_S = 2 \pm 0.15\mu s$ (SLS)

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FIGURE 3. INTERROGATION PULSE TIME RELATIONSHIPS

Alternatively, the P1-P3 side lobe power level received by aircraft A in figure 4 is much lower level and is below the power level of P2 received from the omni antenna. The transponder in aircraft A detects the level of P2 as greater than P1 and suppresses its reply. In actual practice, the P2 power level from the omni is adjusted sufficiently high to cover the side lobes but low enough to allow good main beam penetration and coverage.

TRANSPONDER REPLY.

Upon proper interrogation, the airborne transponder generates and transmits a reply pulse train encoded with either the aircraft's identity or pressure altitude, depending on the mode of interrogation. The reply consists of two framing pulses (F1 and F2) spaced 20.3 μs apart; 12 data pulses, and one special purpose pulse position, all spaced in increments of 1.45 μs from the first framing pulse; and a special position identification pulse (SPI) spaced 4.35 μs after last framing pulse. The reply pulse train is shown in figure 5 and is 20.3 μs duration for either mode of interrogation.

In the case of mode 3/A interrogation, aircraft identity is encoded in the A B C D pulses providing a capability of 4,096 (2^{12}) discrete codes. For mode C, the aircraft altitude is encoded in these same A B C D pulses, providing altitude capability from -1,000 feet to +126,700 feet in 100-foot increments.

The X pulse position indicated in the reply in figure 5 is used by the military. The SPI pulse is the "ident" pulse transmitted upon request of the

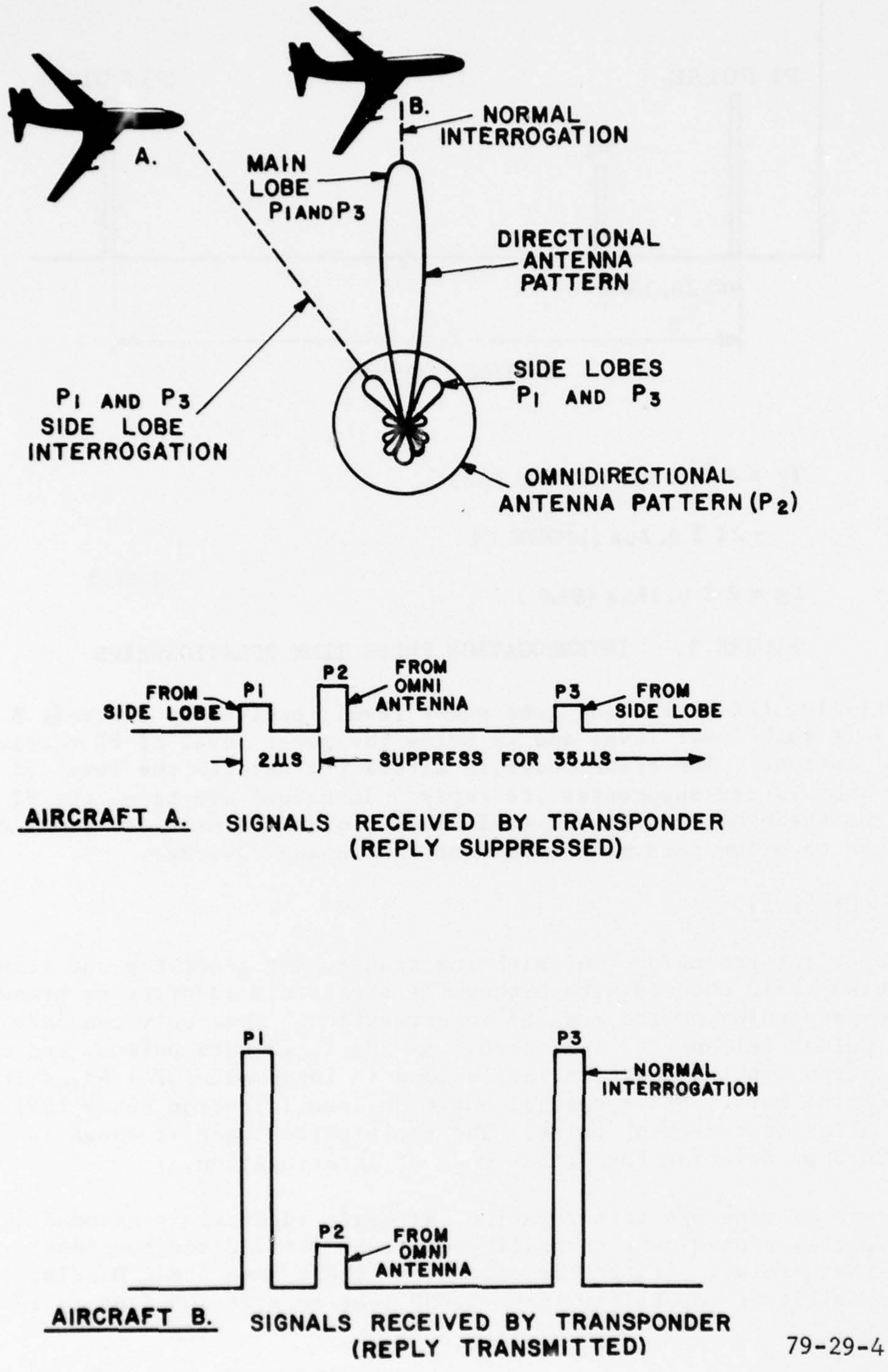
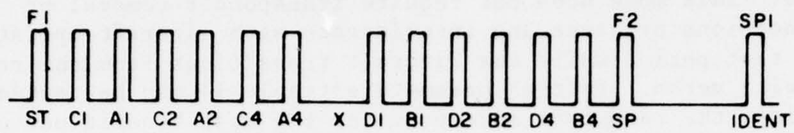


FIGURE 4. SLS OPERATION

controller in mode 3/A only. This normally results in special indications on the air traffic controller's display which identify the particular aircraft responding to the ident request.



REPLY CODE 7777 WITH IDENT

FIGURE 5. REPLY PULSE TRAIN 79-29-6

OTHER REQUIREMENTS.

FAA Order 1010.51A, the ATCRBS national standard, defines other requirements and characteristics of both the interrogation pulse train and the reply. These requirements include pulse shape, duration, timing relations, relative amplitudes, dead time, suppression time, etc. Requirements for specific parameters will be discussed in pertinent sections of the TPA description.

TRANSPONDER PERFORMANCE ANALYZER

The TPA is an automated, mobile test system designed to test and determine aircraft transponder performance characteristics in the operational, real world environment. Three test modes were considered in the design; airborne, bench, and ramp tests. Procedures and techniques for measurement comply with the MOC unless specified otherwise by the national standard.

AIRBORNE TEST.

The airborne mode is not performed due to the variability of the test conditions and complexity of equipment required to perform the tests. Generally, parameters requiring measurement of signal level cannot be made in airborne tests due to uncontrolled variables such as space loss, antenna gain, vertical lobing, etc. Other parameters involving measurement of time can be made, but with difficulty and sacrifice of reliability in the measurements.

BENCH TEST.

The bench test mode is the most thorough and complete of the three modes; however, it does require transponder removal from the aircraft. This is highly undesirable for reasons of time, manpower, and convenience. Further, the transponder is not tested in its normal operating environment, including the antenna, cables, and coupling. Bench tests conducted in the TPA do not include bandwidth, reply rate limit, and sensitivity to continuous wave (CW) or interference, and are limited to varying only one parameter at a time.

RAMP TEST.

The ramp test mode is the most productive, expedient, and cost effective of the three modes. This mode does not require transponder removal or hard-wired connections or cause any interference with aircraft operation except a short test period while the aircraft transitions from the ramp to the runway or vice versa. Fifteen parameters (table 1) can be tested in this mode. In summary, the ramp test mode provides the most benefit per unit cost and is the configuration described in this document.

TABLE 1. MEASURABLE PARAMETERS

1. Minimum Trigger Level (MTL) (Sensitivity)
2. Reply Power Output
3. Reply Frequency
4. Side Lobe Suppression (SLS) Decoding Accuracy
5. Mode 3/A Decoding Accuracy
6. Mode C Decoding Accuracy
7. P1/P2 Power Ratio Required for Suppression versus Signal Level
8. Dead Time
9. Suppression Time
10. Pulse Width
11. Pulse Spacing (Pulse-to-Pulse)
12. Pulse Jitter (Pulse-to-Pulse)
13. Mode 3/A Delay Time
14. Mode C Delay Time
15. F1-F2 Spacing

TPA GENERAL DESCRIPTION

The TPA is housed in a bus-type vehicle (figure 6) for maximum mobility and handling ease. The electronic equipment consists of a special low-power transmitter/oscillator, an AN/UPX-14 beacon receiver, a pulse mode generator (PMG), RF control unit, reply processor, digital clock, computer buffer, computer with magnetic tape and disk storage, a display terminal with hard copy printer, and other elements necessary for timing, control, analog-to-digital (A/D) conversion, etc. Figure 7 is a block diagram of the TPA system.

In normal operation, the controller processor computer issues commands or instructions to the PMG which establishes the pulse rate or repetition frequency and spacing between interrogation pulses. This control of repetition rate and pulse spacing is used in measurements of transponder dead time, suppression time, decode accuracy, and other time dependent parameters. The PMG also controls the RF control unit which contains diode switches,

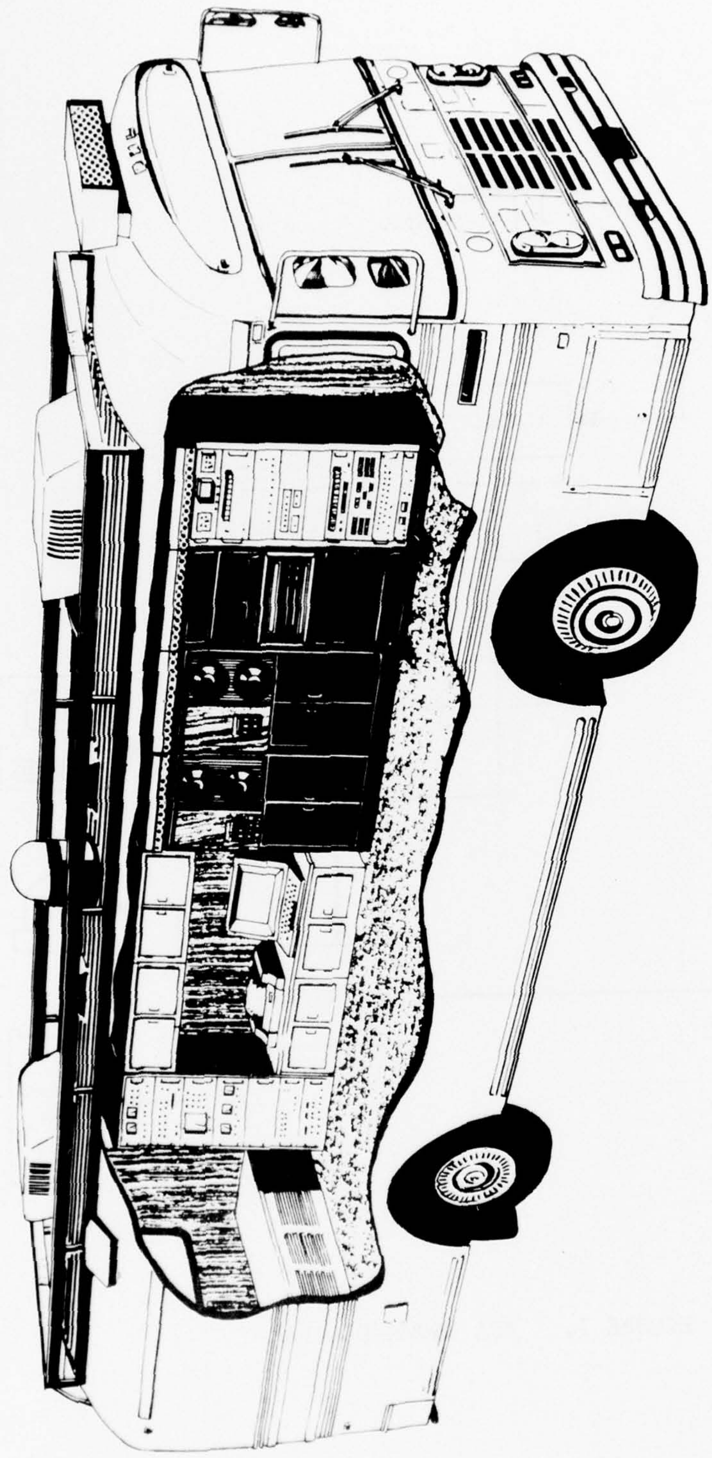


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FIGURE 6. TRANSPONDER PERFORMANCE ANALYZER VAN

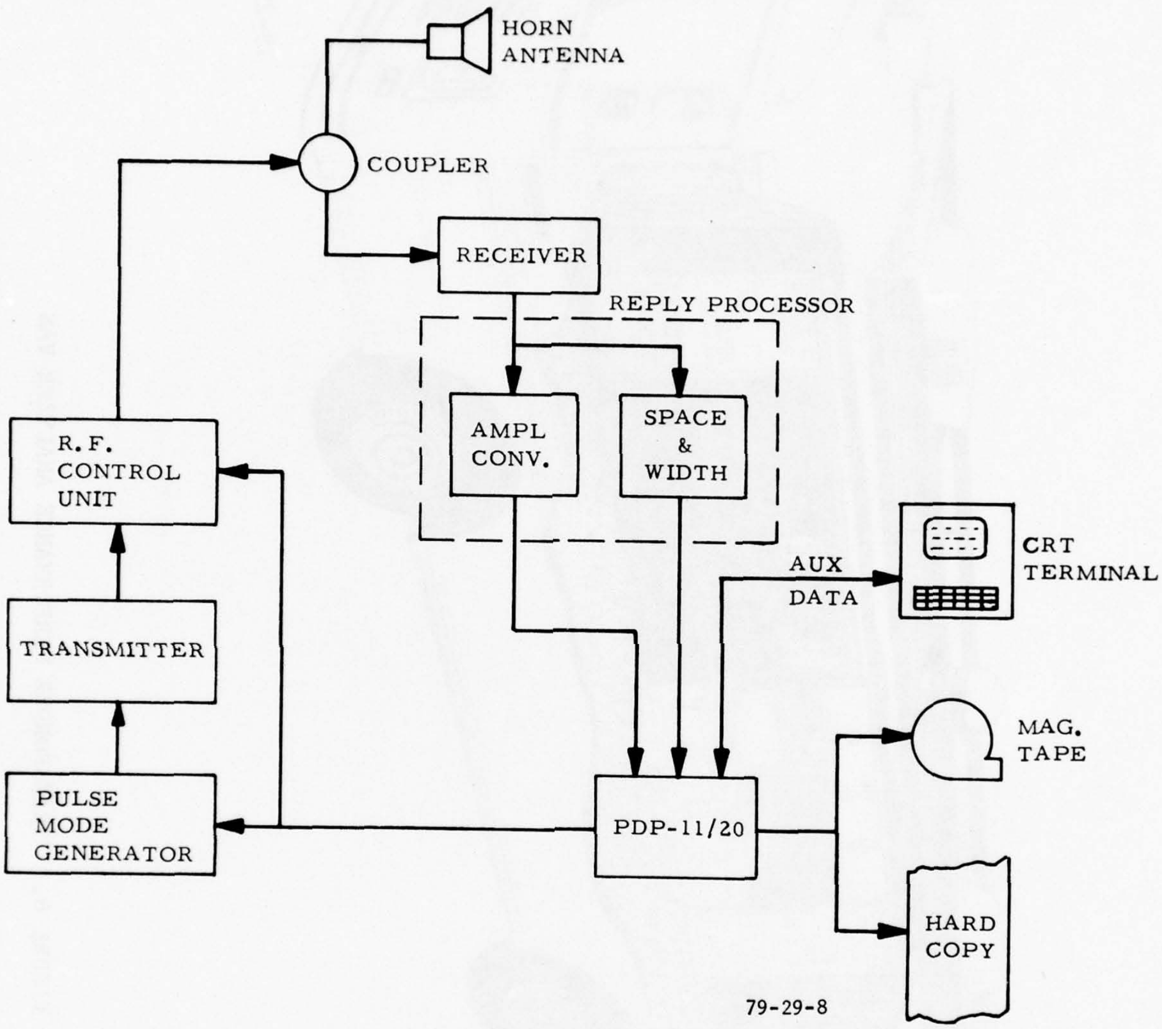

FIGURE 7. TPA BLOCK DIAGRAM

attenuators, and circuitry for amplitude and path selection of the RF output from the transmitter. In the ramp test mode, only a directional horn antenna is used, and all pulses are transmitted and received via the horn (see figure 8).

The transponder reply is processed through the receiver, intermediate frequency (IF) amplifier, and various circuits for measurement of pulse amplitude, width, spacing, etc., and is eventually recorded on magnetic tape for future analysis. Pulse width, spacing, and timing are measured using a 100-MHz oscillator time source. The cathode-ray tube (CRT) terminal provides a visual output during test and maintenance procedures, and the printer provides a hard copy printout for immediate analysis.

TEST PROCEDURES.

The normal procedure for ramp testing is to (1) locate the TPA alongside a taxi ramp, (2) position the aircraft over a calibrated position marker (figure 9), and (3) have the aircraft transmit a specified beacon code for approximately 30 seconds, then continue on. When the aircraft is moved into the calibrated position, space loss, horn antenna gain, and cable losses have all been predetermined. Measurement and analysis of the 15 parameters are then possible.

INITIALIZATION AND CALIBRATION.

The initialization and calibration process requires thorough bench testing and calibration of a transponder to be used as a standard. The power output, sensitivity, pulse spacing, pulse width, and other parameters are carefully measured and calibrated. The transponder is then connected in a closed loop, and the TPA equipment inside the bus checked and calibrated on a daily basis during the test period. Closed loop readings significantly different from the initial setup are used as indications of problems within the system. The transponder is then connected to an antenna which is positioned over the designated test mark on the taxiway. Software parameters in the TPA are then adjusted with offsets to provide the proper calibrated values when the transponder is interrogated with the horn. The offsets are site parameters and vary from site to site, dependent on immediate surrounding surface area (concrete, grass, macadam). This technique accounts for cable losses, coupling losses, etc, within the system. All other test transponders are then compared with this standard.

The taxiway marker is normally located as near the TPA side of the taxiway as reasonably possible, then a distance of 50 feet measured to the front of the horn. The horn position is also marked so the horn can be located back to the same position. The distance and horn height above ground (30 inches) were determined by experimental measurements as an optimum to cover all the various types of general aviation aircraft and antenna placement. Horn height adjustments will result in a 1- to 2-dB change. However, aircraft type (airframe) and antenna placement on the aircraft present far greater variations and problems. The aircraft surface area, airframe design, antenna

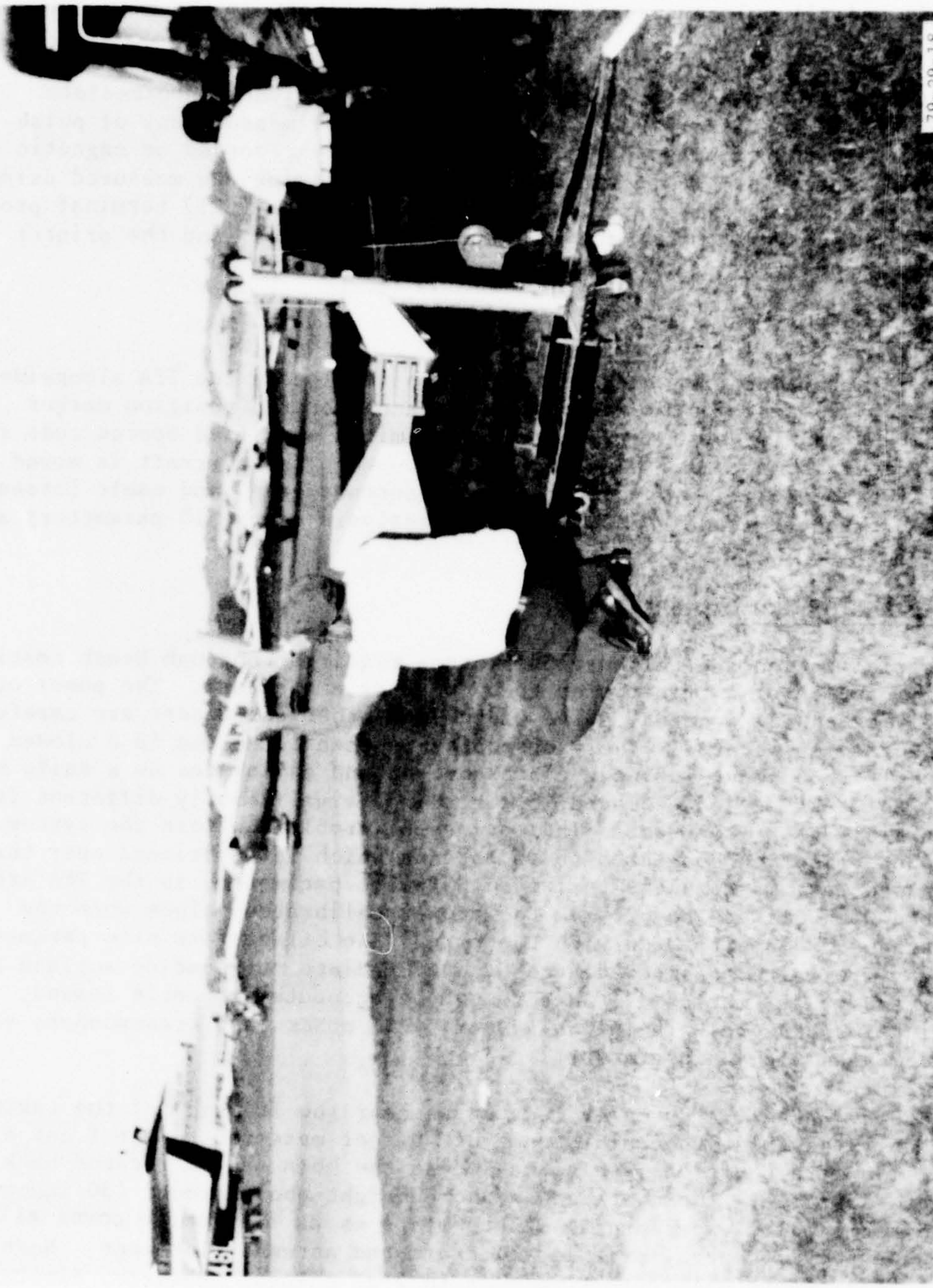

FIGURE 8. TPA HORN

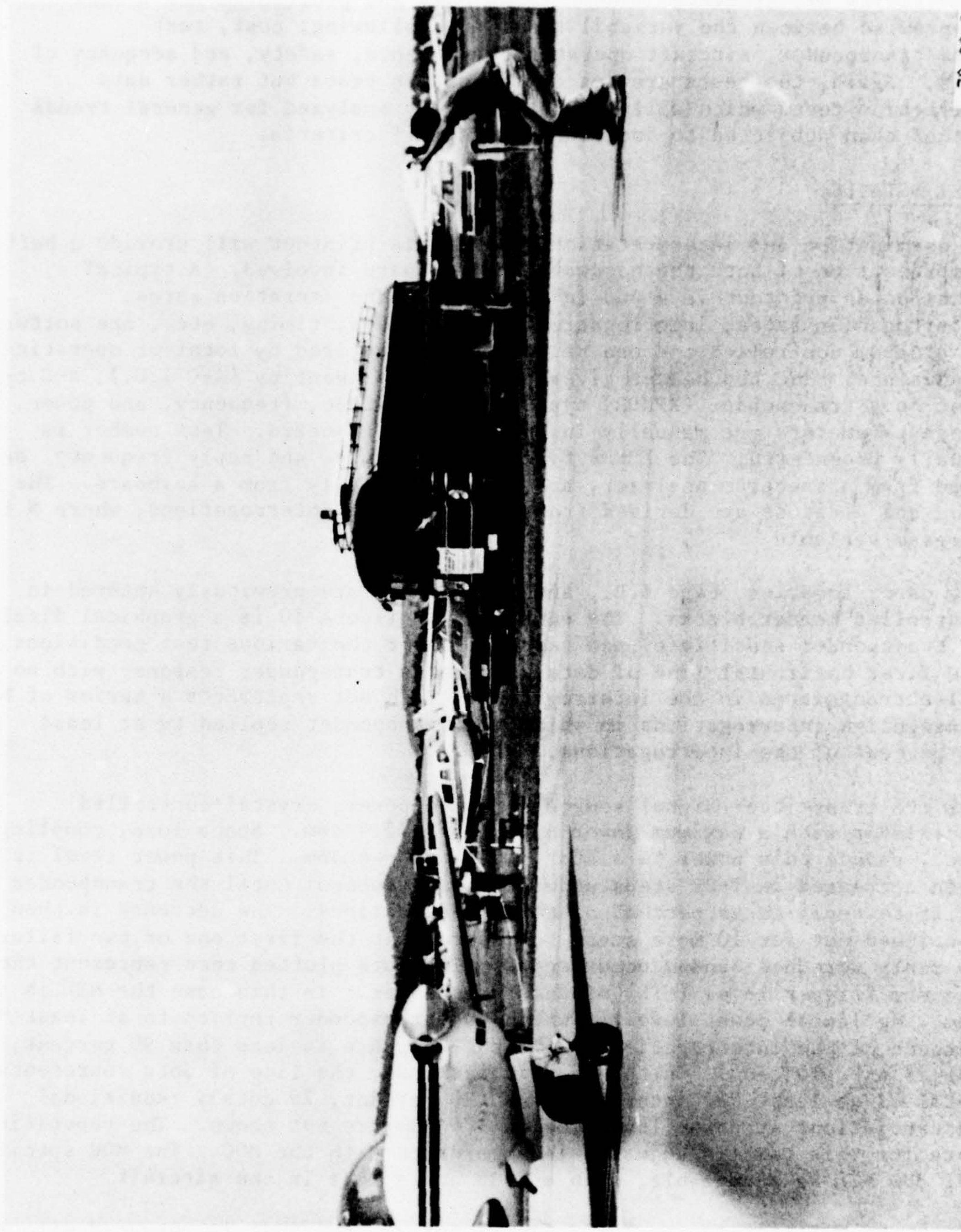

FIGURE 9. TPA OPERATION

placement, and height above ground are all factors which affect the power and sensitivity measurements. These techniques and procedures are a best compromise between the variability of the following; cost, test time/transponder, aircraft operator convenience, safety, and adequacy of data. Again, the tests are not certification tests but rather data collection tests which will be statistically analyzed for general trends rather than subjected to individual pass/fail criteria.

TEST DETAILS.

An examination and interpretation of the data printout will provide a better comprehension of both the hardware and software involved. A typical transponder printout is shown in figure 10. The iteration rates, interrogation rates, interrogation signal levels, timing, etc., are software or program controlled and can be changed as required by local or operating conditions. The top header gives the aircraft identity (A-C I.D.), A-C type, test No., transponder (XPNDR) type, code, altitude, frequency, and power. These parameters are manually inserted from a keyboard. Test number is usually preentered. The XPNDR type, if available, and reply frequency, as read from a spectrum analyzer, are entered manually from a keyboard. The code and altitude are derived from N consecutive interrogations, where N is a program variable.

The date, location, tape I.D., and file number are previously entered in controlled header blocks. The next area in figure 10 is a graphical display of transponder sensitivity and response under the various test conditions. The first horizontal line of data represents transponder response with no P2 pulse transmitted in the interrogation. Each dot represents a series of N consecutive interrogations in which the transponder replied to at least 90 percent of the interrogations.

The TPA transmitter/signal source is a low-power, crystal-controlled oscillator with a maximum power output of +25.4 dBm. Space loss, coupling, etc., reduce this power to a start level of -46 dBm. This power level is then decreased in 1-dB steps under software control until the transponder fails to reply to 90 percent of the interrogations. The decrease is then continued out for 10 more steps to insure that the first one or two failures to reply were not random occurrences. The dots plotted then represent the minimum trigger level (MTL) of the transponder. In this case the MTL is -74 dBm, the lowest power level at which the transponder replied to at least 90 percent of the interrogations. (If the response is less than 90 percent, a dot is not plotted.) In this particular case, the line of dots represents a total of at least 580 interrogations (20 per dot, 29 dots). Additional interrogations at power levels below -74 dBm are not shown. The repetition rate for this test is adjusted in accordance with the MOC. The MOC specifies -71 dBm MTL as acceptable, with a 3-dB cable loss in the aircraft.

After the MTL test is completed (no P2 pulse), the test is repeated with the P2 pulse transmitted, but at a power level -18 dB below the level of P1. Again, the power levels are decreased from maximum TPA power down to the

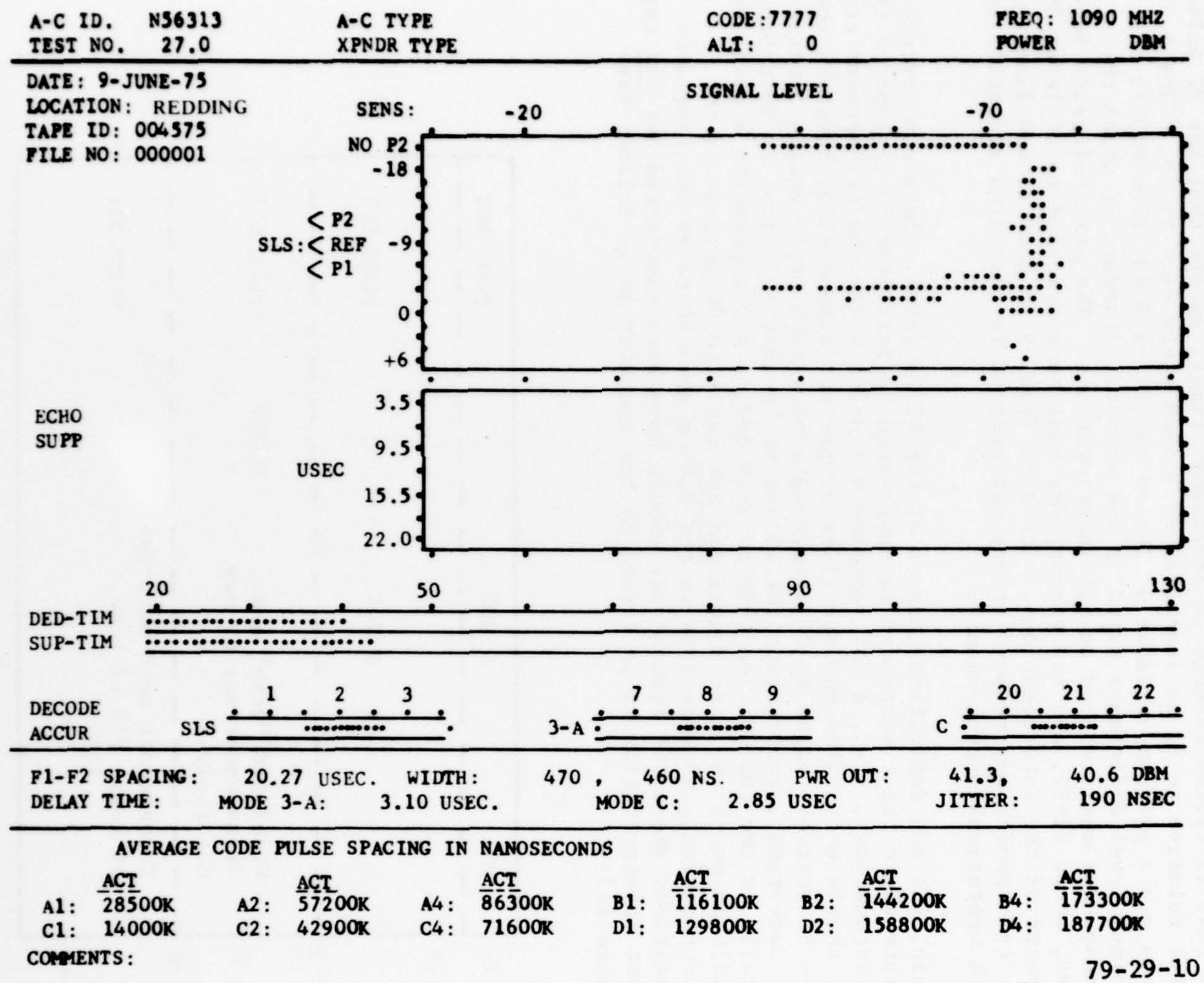

FIGURE 10. COMPUTER PRINTOUT SAMPLE

level where the transponder fails to reply 90 percent of the time (plus 10 more steps as before). In this area, a dot is plotted if the transponder fails to respond to at least 90 percent of the interrogations. As shown in the example, this particular transponder failed to respond to at least 90 percent (18 out of 20) of the interrogations at the -75 dBm power level. The test is cycled through 16 additional times, except that the P2 pulse level relative to P1 is increased in 1.5-dB steps each cycle. (The 1.5-dB steps are a program variable.) The -9 dB (P2 is 9 dB below P1) is the minimum level difference cited in the national standard at which the transponder must respond to all interrogations. The next reference level is 0 dB, where P2=P1, and the transponder must be suppressed to at least 99 percent of the interrogations. The area from -9 to 0 dB is undefined, and the transponder may respond or may not respond in this area and still comply with operational requirements.

Again, the dot definition changes at the P2≥P1 level. Dots now represent points where the transponder is suppressed to less than 95 percent of the interrogations; i.e., a dot represents a point where the transponder replies, but should not. (The MOC specifies 99-percent suppression, however, the TPA uses 95 percent, based on 20 interrogations. Each reply equals 5 percent, or, conversely, suppression for 19 out of 20 interrogations is 95 percent.) Recall, in the top portion (-18 to -1.5 dB), a dot represents a point or condition where the transponder did not reply to 90 percent of the interrogations, whereas dots in the bottom area (0 to +6 dB) represent conditions where the transponder should have been suppressed but did reply. Chart interpretation as performed by the computer is as follows (see figure 11):

No P2	MTL	R≥90%	PLOT DOT
-18			
		R<90%	PLOT DOT
-9	Undefined "gray" area. Transponder may or may not reply.	R<90%	PLOT DOT
-0	Transponder must suppress at least 95% of time, R>5%.		PLOT DOT
+6			

R = Percentage of interrogations to which the transponder replied

FIGURE 11. SENSITIVITY CHART INTERPRETATION

ECHO SUPPRESSION. Transponder echo suppression tests are not performed in the TPA because of its limited power. Furthermore, power levels sufficiently high for the test may result in unnecessary interference with other operational systems in the area. This test can be performed in the bench test mode and is normally performed on "off-the-shelf" units. The test is performed by feeding a desensitizing pulse, 50 dB above MTL into the transponder 3.5 μs before the P1 pulse. The desensitizing pulse activates the echo suppression circuitry, then the P1/P3 pulse levels are adjusted so that the transponder just replies to 90 percent of the interrogations (450 out of 500). The desensitizing pulse (P0) is then moved forward in time (interval between P0 and P1 increased), and the level of P1/P3 again adjusted to give the 90-percent reply point. These measurements are continued out beyond the 15-μs decay time specified in the MOC. The resultant response is a function of the transponder echo suppression curve. A typical plot is shown in figure 12. Dots are points where the transponder is suppressed. Care must be taken during the measurements to avoid P0-P1 pulse time intervals used to initiate the various reply modes; i.e., time intervals coinciding with mode interrogations.

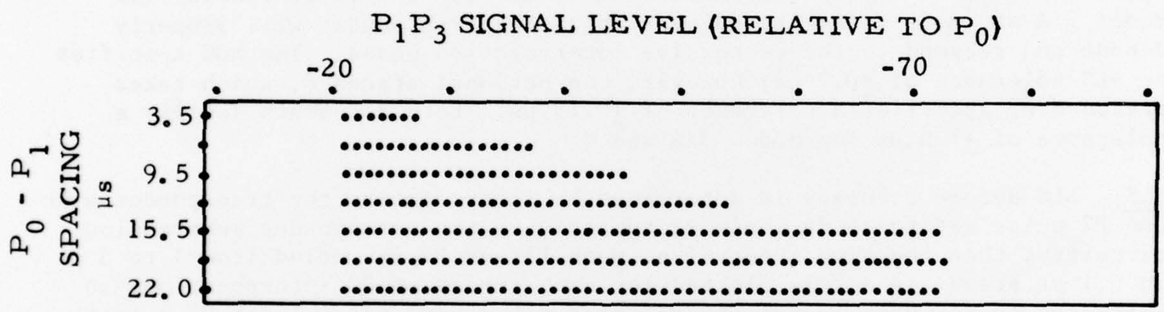

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FIGURE 12. ECHO SUPPRESSION

DEAD TIME. The next area of the printout (figure 9) pertains to "dead time" and "SLS suppression time." Definitions of dead time and suppression time are given in the MOC. Dead time is measured by using two consecutive interrogations (interrogation pairs) and checking for response from the second interrogation. Both interrogations are of proper pulse amplitude and spacing; however, the time interval or spacing between interrogations is varied, starting at 20 μs, then increased in 1-μs steps until the transponder consistently replies to 90 percent of the second interrogations. The interrogation "pair" repetition rate is reduced to 250 pairs per second to avoid transponder reply rate limits. Each dot on the printout represents a series of "n" interrogation pairs (2 n interrogations total) in which the transponder replied to the first but not the second interrogation at least

90 percent of the time. The result is then a plot of transponder dead time. Dead time in the example is 40 μs.

SIDE LOBE SUPPRESSION. Side lobe suppression (SLS) time is measured with the same technique using interrogation pairs (not to be confused with the P1/P2 suppression pair) and varying the time interval between interrogations. The P2 pulse level of the first interrogation is set equal to +6 dB above P1 to be certain of activating or triggering the SLS circuitry. The P2 pulse is not used in the second interrogation (P2 = 0), and transponder response is checked, starting at 20-μs separation between the first and second interrogations. The transponder is interrogated for a series of 20 tries. If the transponder does not reply (is suppressed) for at least 95 percent of the time, a dot is plotted. The time interval between interrogations is then increased by 1-μs interval until the transponder consistently replies to 90 percent plus 10 more intervals of the "2nd" interrogations. The resultant plot is the transponder suppression time. FAA and MOC requirements for suppression time is 35 $\pm$10 μs.

DECODE ACCURACY. SLS, mode 3/A, and mode C decode accuracy is shown in the next area of the printout (figure 10). This is a measure of the pulse spacing tolerance (P1-P2 spacing for SLS detection and P1-P3 spacing for modes 3/A and mode C detection) over which the transponder will properly decode and respond to the respective interrogation modes. The MOC specifies an SLS tolerance of $\pm$0.7 μs; however, the national standard, which takes precedence, specifies a tolerance of $\pm$0.15 μs. Both documents specify a tolerance of $\pm$1.0 μs for modes 3/A and C.

SLS. SLS decode accuracy is determined by interrogating the transponder with the P2 pulse set to +6 dB above P1 to activate the transponder suppression circuitry, then the time interval between P1 and P2 is varied from 1 to 3 μs in 0.1-μs steps. A dot is plotted for each series of 20 interrogations in which the transponder is suppressed (does not reply) to at least 99 percent of the interrogations. The resulting plot is then a measurement of the times the transponder detected the P2 pulse and suppressed as required.

MODE 3/A AND C. The mode 3/A and mode C decode accuracies are measured by eliminating the P2 pulse and varying the time interval between P1 and P3. For mode 3/A the interval is varied from 7 to 9 μs in 0.1-μs steps. For mode C, the time interval is varied from 20 to 22 μs, again in 0.1-μs steps. In each case, a dot is plotted if the transponder replies to 90 percent of the interrogations.

PULSE SPACING. The lower portion of the printout pertains to transponder reply pulse characteristics. The numbers are in straightforward decimal numbers. The F1-F2 spacing is the bracket pulse spacing measured with a 100-MHz clock. Pulse width and power-out are given for F1 and F2, respectively. Pulse width is measured again using the 100-MHz clock, and power-out is processed through A/D conversion circuitry. The delay time, pulse-to-pulse jitter, and average pulse spacing are measured using the 100-MHz source and gate circuits to control the number of cycles gated

through to holding registers. The holding registers are then dumped to buffer memory and input to the computer upon detection of a proper response.

It is important to note that, in all tests, the computer and software control the number of samples, time intervals, dot representations, etc.; and these parameters can be changed by software modification. The particular number chosen (20) appears to be a reasonable compromise between data quality and aircraft ramp time. This time becomes important to the aircraft operator and to ground traffic control to avoid delays or traffic backup.

HARDWARE DETAILS.

The TPA system is composed of both commercially available and specialized National Aviation Facilities Experimental Center (NAFEC) designed/constructed equipment, all interfaced and assembled into an operating system. Figure 13 is a functional block diagram depicting major elements of the system. As seen from the diagram, the controller processor controls the transmitter via the PMG and RF section. The transponder reply is routed through the receiver to the decoder, A/D converter, and other data collection circuits. The outputs from these circuits are then buffered and fed into the controller where they are recorded on magnetic tape or disc.

CONTROLLER PROCESSOR. The controller processor is a Digital Equipment Corporation minicomputer, model PDP-11/20, with 24k of core memory, two magnetic tape drives, one disc drive, a printer, and various buffered interfaces. All TPA timing, control, and data collection commands are issued under software control. System timing, sampling rate, points per sample, and other test parameters may then be changed by modification to the software.

PULSE MODE GENERATOR. The PMG is a NAFEC-designed unit which converts the computer commands into specified pulse relationships and generates the necessary control signals for system operation. The P1, P2, and P3 pulse intervals and widths are generated in the PMG. It should be noted that the pulse widths and amplitudes are constant, and only the timing relationship is varied within the PMG; however, amplitude control signals are generated in the PMG.

The PMG (figure 14) consists of a 20-MHz oscillator, divide-by-2 circuit, pulse repetition timing control, reset control, five divide-by-10 counters, computer-controlled selector circuits, compare circuits, drivers, and RF output central registers. Briefly, the PDP-11 establishes the desired interrogation pulse spacing and relationships in a software control, which is output and stored in the selector circuits. This is a digital number which defines the relative time for the specified pulse P1, P2, and P3 to occur. Meanwhile, the 20-MHz oscillator output is divided by 2 to 10 MHz which clocks the reset control and PRF timing control.

The 10-MHz clock is also gated through to the time control counter. This counter is a five-stage, divide-by-10-per-stage counter which counts time to 0.1-μs increments. The counter outputs are then compared in compare circuits

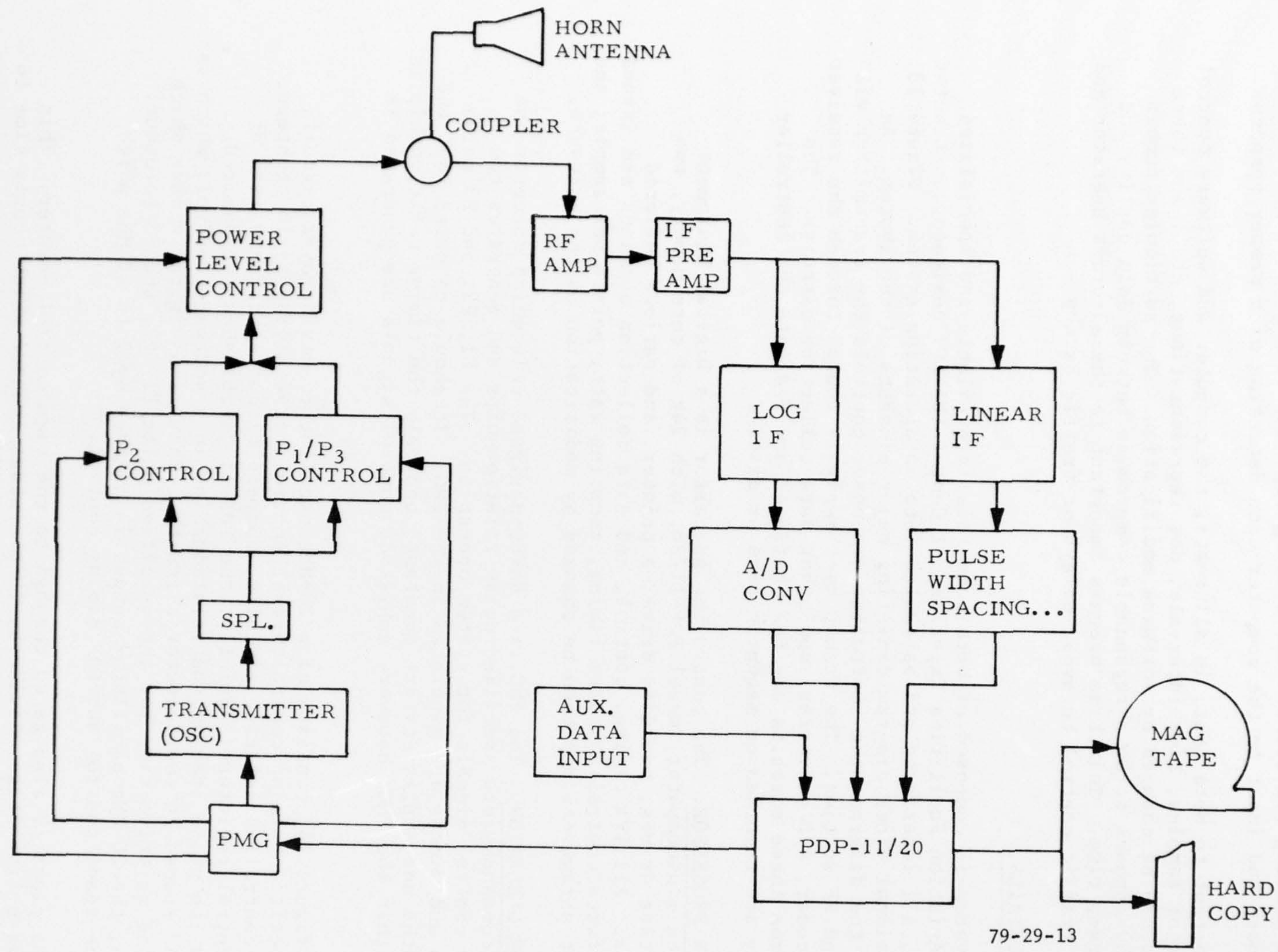
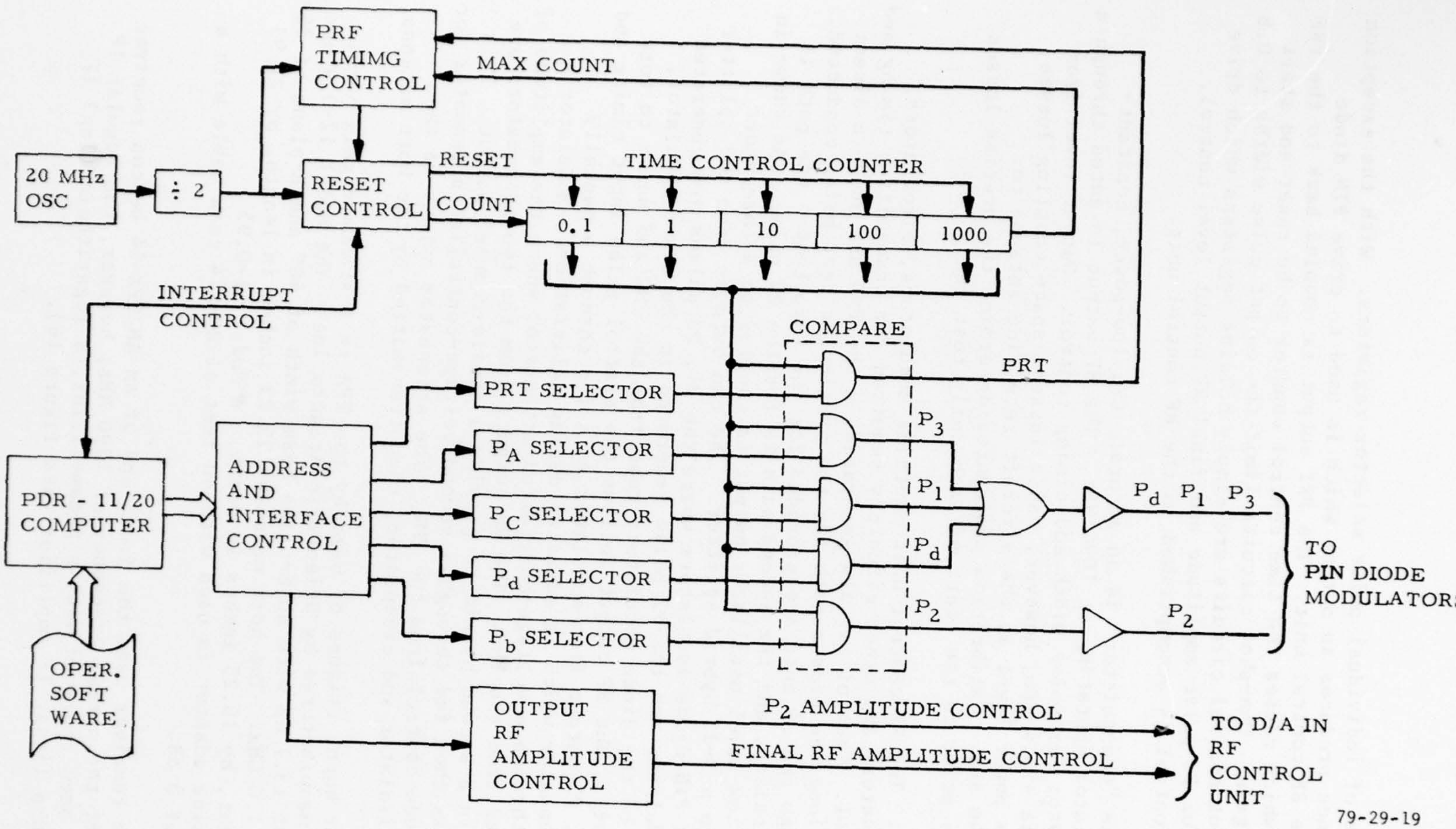


FIGURE 13. TPA FUNCTIONAL BLOCK DIAGRAM



FIUGRE 14. PMG BLOCK DIAGRAM

with the contents of individual pulse selector registers. With the exception of PRT, coincidence produces an output which is used to drive PIN diode modulators in the RF control unit. The PRT output is coupled back to the PRF timing circuit, which causes the time control counter to be reset and start the count over again. One-shot circuits limit the output pulse widths to 0.8 μs. The RF output control circuits are simply holding registers which drive A/D converters for P2 pulse amplitude and final RF output level control. This amplitude control is accomplished in the RF control unit.

TRANSMITTER. The "transmitter" is an accurate CW, low-power, constant-amplitude oscillator operating at 1030 MHz. The RF output is gated through a PIN diode modulator for pulse width and timing control. Output level from the oscillator is +25.4 dBm; however, cable losses, space coupling losses, etc., reduce the power level at the aircraft receiving antenna to approximately -46 dBm. Calibration procedures determine the precise losses and power levels prior to the start of each daily test run.

RF CONTROL UNIT. The RF control unit contains modulators, circulators, couplers, attenuators and other circuitry required for transmitter timing and amplitude control. Control signals generated in the PMG are used to direct the RF energy along the proper path for the particular test being conducted. Two paths through the RF unit are provided for the ramp test. One path is for the P1, P3 pulses, and the second path is for the P2 pulse. As shown in figure 15, the low-level oscillator output is coupled to a three-port circulator, then a 3-dB hybrid splitter. The two outputs from the splitter are fed through PIN diode modulators where the P1, P3 pulses are generated through one modulator and the P2 pulse generated in the other modulator. Control inputs to the diode modulators come from the PMG and serve to turn the RF on and off. The RF output follows the control pulse input timing and width. The P1, P3 output from modulator A is fed through a manually controlled attenuator which is adjusted during calibration. Modulator B output is fed through a voltage-controlled attenuator where the amplitude of P2 is controlled from the PMG. The RF outputs from the two attenuators are then combined in a second hybrid to provide a single-channel output. This single output is then fed through a second voltage-controlled attenuator for overall amplitude control from the PMG. The attenuator output is then coupled to an isolator and circulator, then transmitted by the horn antenna.

This particular horn, (figure 8) used by the TPA is a standard gain horn, Model 12-0.9, manufactured by Scientific Atlanta Inc. The Model 12-0.9 has a nominal gain of 13.7 dB with an E-plane beam width of 40° and H-plane of 35°, calibrated at 1.0 GHz. The horn measures 23.23 inches in length, by 21.93 inches in height, by 16.25 inches in width. A Model 11-0.95 coax-to-waveguide adapter is used with 40 feet of RG-214 coax cable with a nominal loss of 3 dB.

RECEIVER. The receiver uses the front end of an AN/UPX-14 beacon receiver and operates at the normal frequency of 1090 MHz; however, the regular IF amplifier has been replaced with a preamplifier, a logarithmic (log) IF amplifier, and a linear IF amplifier (see figure 16).

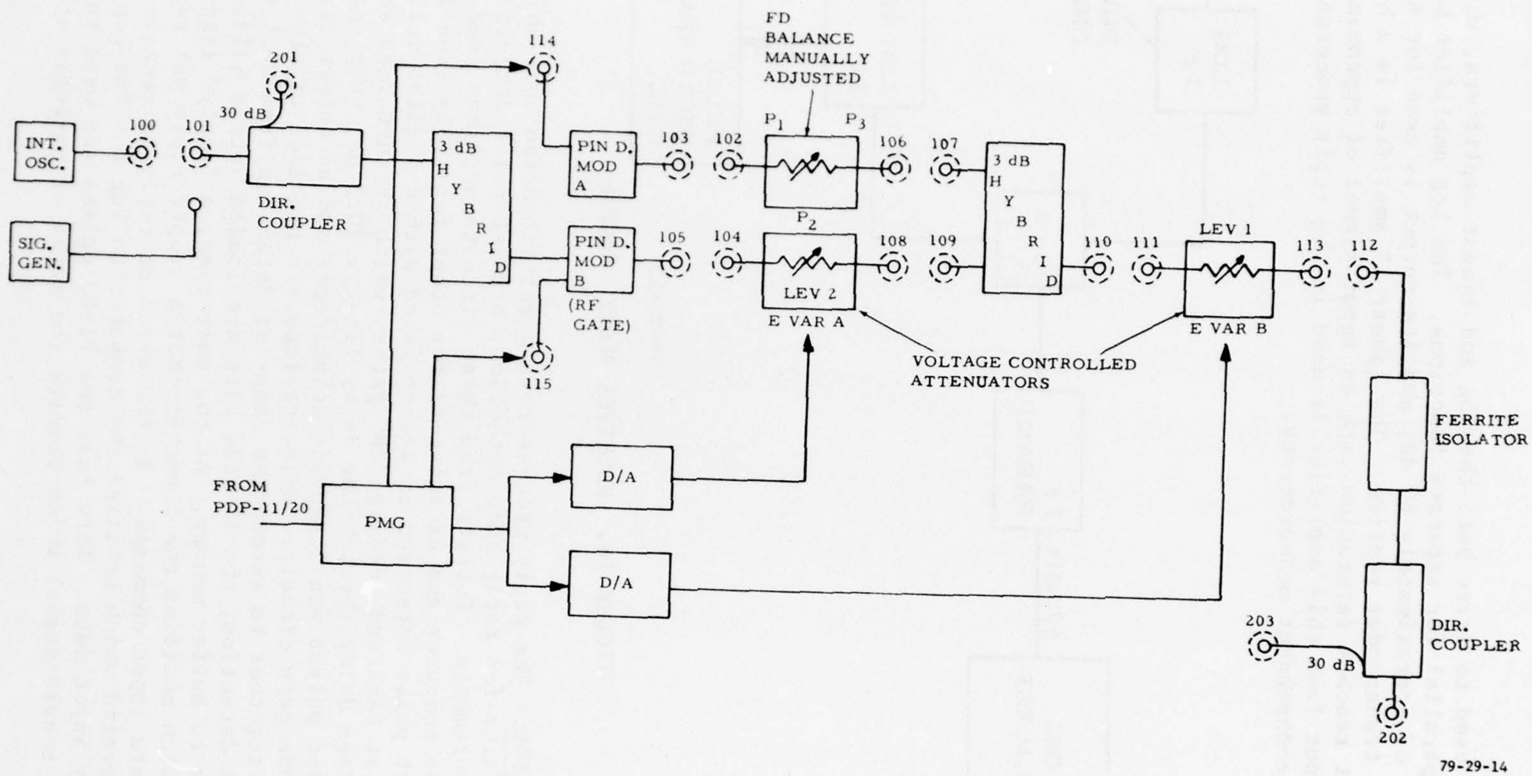


FIGURE 15. RF CONTROL UNIT

The preamp is used to drive both the log and linear amplifiers, which are connected in parallel for separate functions. The log amplifier has a wide dynamic range of approximately 60 dB, and its output is used for A/D conversion of transponder replies. The linear IF amplifier is a high-gain amplifier that reaches saturation with an input signal of approximately -65 dBm. Output from this amplifier is used in the reply processor for pulse width and time-dependent measurements.

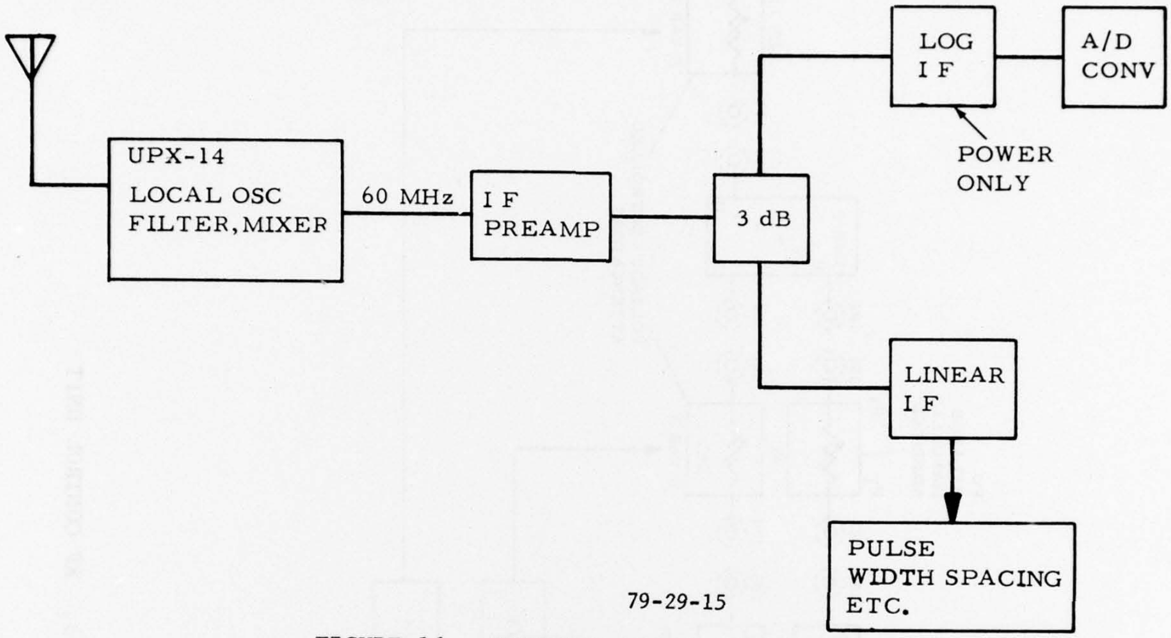


FIGURE 16. RECEIVER BLOCK DIAGRAM

REPLY PROCESSOR. The reply processor is a multifunction unit which contains various circuits for reply code detection, bracket pulse detection, and pulse spacing measurements. Outputs from these circuits are then used as data inputs to the computer and as triggers for other functions (see figure 17). F1-F2 bracket pulse detection is accomplished with a digital delay line having taps at each end feeding "OR" gates, which in turn feed an "AND" gate. The propagation delay through the delay line is 20.3 μs, such that properly spaced bracket pulses would provide coincidence and an output from the bracket decode gate circuit. Adjacent taps are provided off the delay line and "OR'ed" together to extend the range of detection from 20.1 to 20.5 μs. Upon bracket detection, the 12 code bits are loaded into a holding register for transfer to buffer memory. At the same time, a "reply" signal is generated which notifies the computer that a proper reply was received and initiates data input commands. In the event no reply is received, a signal is also generated which notifies the computer to log the "no reply" but does not read any input data. Note that the P1-P3 pulses are used to generate an "accept" or enable signal which permits the reply or no-reply signals to be

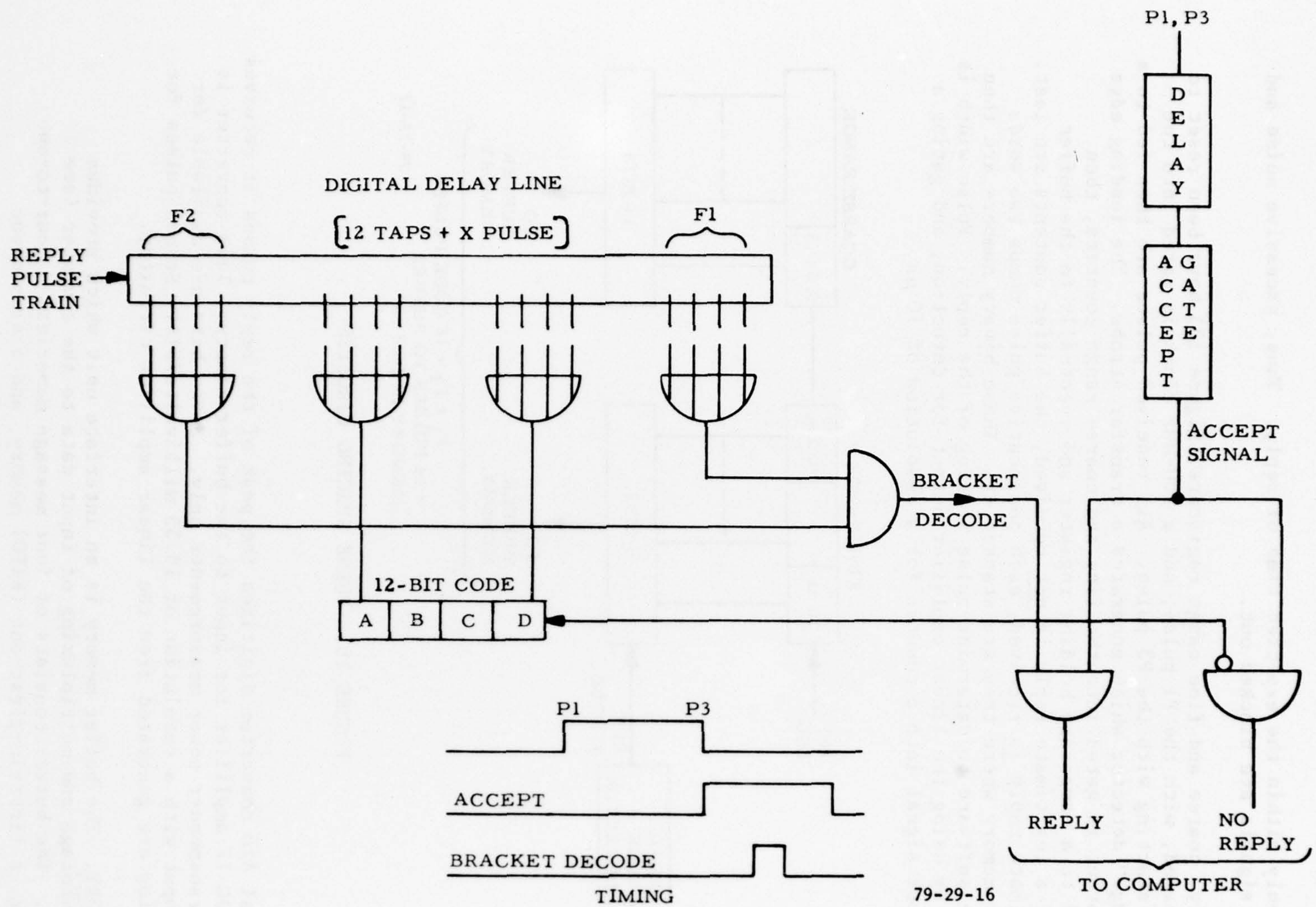


FIGURE 17. BRACKET DETECTION

generated only within the expected time of reply. Thus, excessive noise and extraneous signals are blocked out.

Concurrently, coarse and fine range registers (figure 18) have been reset to zero or cleared, with the P1 pulse, and a 100-MHz clock is gated into the registers, starting with the P3 pulse. All received pulses are then fed to a "leading edge" detector which generates a transfer strobe. The leading edge detector output is gated into the fine and coarse range counters, then transferred to a temporary holding register and eventually to the buffer memory. If a legitimate reply is not received, the buffer contents are lost. If a legitimate reply is received, each consecutive pulse dumps two words into buffer memory where they are stacked up. These binary numbers are then used by the software to determine pulse spacing of the reply. Pulse width is determined by using the linear amplifier output for detection, and gating a 100-MHz clock signal into a counter for a resolution of 10 μs.

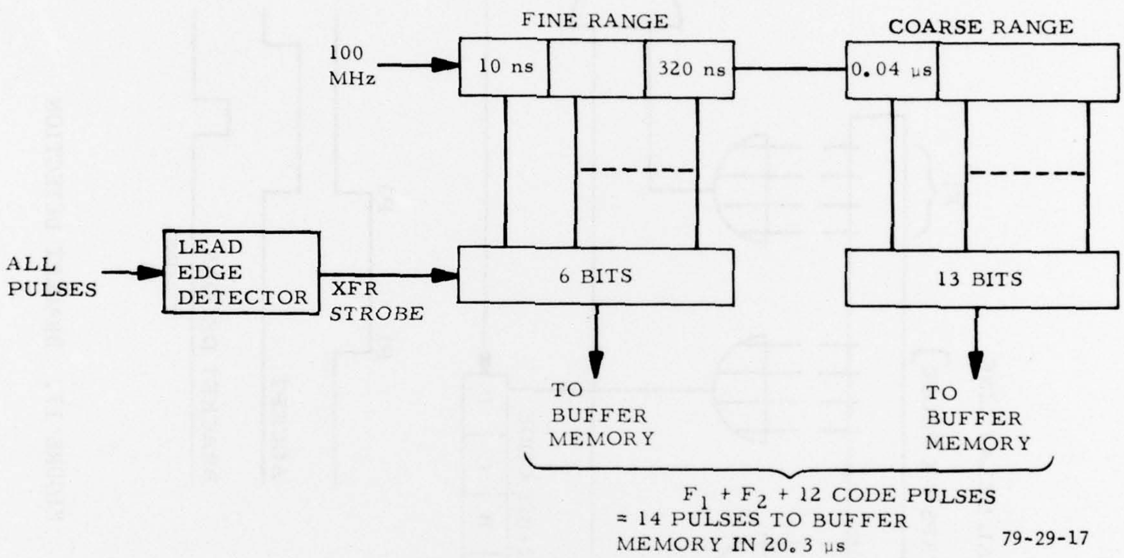
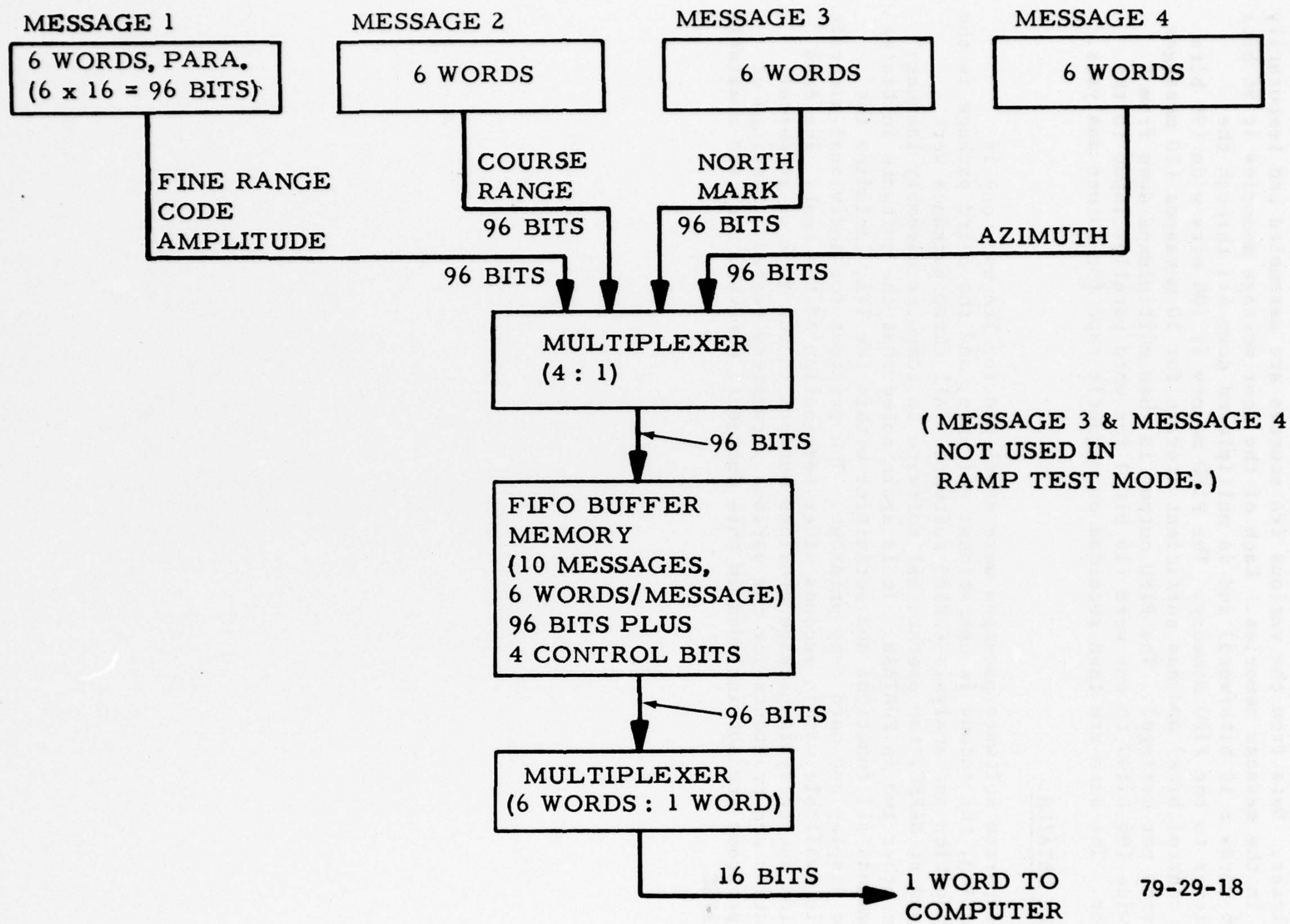


FIGURE 18. PULSE SPACING CIRCUITS

A commercial A/D converter digitizes the peak of the reply pulses it receives from the LOG IF amplifier for input to the buffer memory. This converter is used for transponder power measurements only. Seven bits are available for computer input with a resolution of 19.53 millivolts/bit. Strobe pulses for A/D operation are generated from the linear amplifier circuitry.

BUFFER MEMORY. The buffer memory is an interface unit which provides temporary storage and multiplexing of input data to the computer (see figure 19). The buffer consists of four message memories, a four-to-one multiplexer, a first-in-first-out (FIFO) memory, and a six-to-one



FIUGRE 19. BUFFER MEMORY

multiplexer. Data from the various TPA sources are assembled and temporarily stored in the message memories. Each of the four message memories is 96 bits wide (6 words x 16 bits/word) and is multiplexed down 4:1 through the multiplexer to the FIFO memeory. The FIFO memory is 100 bits wide (96 bits plus 4 control bits) and has sufficient storage for 10 messages (10 messages of 6 words per message). The FIFO output is then multiplexed down from 6 words wide (96 bits) to one word (16 bits) for word parallel input to the computer. The data are then recorded on magnetic tape for future analysis.

SOFTWARE DETAILS.

Three separate software packages were developed for TPA use; one is calibration, the second is operational software, and the third package is the data reduction and analysis (DR&A) software. All three packages were developed at NAFEC; the operational software in computer assembly language and the other two in FORTRAN. It is again noted that the software initiates and commands all functions and activities within the TPA, including the graphic display and hard copy printout. The printout for individual aircraft tests is available within seconds after termination of the test. The data reduction and analysis package provides outputs in the form of graphical information and printouts for the various parameters tested. Listings of these programs are not included in this document; however, they are available from NAFEC.